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Design of Bio-Mimic Hexapod

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ABSTRACT : *Many attempts have been made till date to imitate physiological characteristics of biological creatures (mainly insects) using different types of joints and actuators. This has given rise to an all new field in robotics, named bio-mimitecs. In this approach we aim to design and simulate a bio-mimic hexapod (6 legged mobile robot) using the minimum possible number degrees of freedom. It has been found that for a legged robot to be advantageous over a wheeled robot, minimum 3 degrees of freedom is needed per leg. The design presented in this report makes use of two simple revolute joints per leg and the required motion is provided by DC Servo motors. These 2 degrees of freedom will propel the robot in the direction of motion. An additional 1 degree of freedom is desired at each leg to achieve the steering of the robot. This third degree of freedom is removed from each leg and taken common to replace by 2 degrees of freedom at the centre of the robot to achieve the desired steering of the robot.*

Once the mechanism is finalized, link geometry will be modeled using any CAD software and later it can be checked on anyCAE software for stress analysis. The Kinematic and Dynamic analysis of Hexapod will be done.

Also a detailed analysis can be carried out to study the variation in torques for different link lengths. This will help in optimizing the dimensions of the hexapod for particular application.

Keywords – *Bio-mimic, Design, Hexapod, Link geometry, Legged robot.*

I. INTRODUCTION

1.1 Background

For decades, researchers have sought to design a fully autonomous, legged walking machine capable of operating in complex natural environments. Development of such machines has been limited by actuators, power sources and control schemes that cannot hope to compete with even some of the “simplest” systems found in the natural world; in contrast, natural organisms have developed a wide range of means by which to loco mote through any terrain imaginable. Biology provides a wealth of concepts to assist robot design. Insects in particular are well known not only for their speed and agility but also for their ability to traverse some of the most difficult terrains imaginable; insects can be found navigating sparse or rocky ground, climbing vertical surfaces, or even walking upside down. Stepping pattern to maintain efficient locomotion with a reduced number of legs. The recognized benefits of legged locomotion have created intense interest in the features and characteristics of the many successful examples we see in nature, specifically insects. Insects can walk on irregular surfaces like leaves and branches almost as well as they can on flat, level ground. They can walk forward and backward, and in some cases even sideways or upside down. Insects can also walk after injury or damage to their legs or even after suffering the complete loss of one or more legs.

1.2 Preference for Legged System

Wheeled vehicle can achieve excellent performance on prepared surface. However, most of the earth surface is unsuitable for such systems. There is an urgent need of mobile systems that can move in terrain that are uneven. Such a terrain will include outdoor environment like forest, desert, soft ground as well as indoor environment. The ground contact in legged machine is not continuous and the leg support is obtained at discrete footholds. Thus, even if terrain were interspersed with sharp rocks local soft spots, it is possible for walking machine to be able to achieve mobility. Legged system also offers additional advantages. They tend to provide active suspension. Another advantage is significant in radioactive or chemically active hazardous environment. Of course legged systems are much more complex than wheeled system and involve coordination of leg and issue of stability and balance.

1.3 Literature survey

Yoseph Bar-Cohen, [10]

In his report named “Biomimetics: mimicking and inspired-by biology”, discussed that how the evolution of nature led to the introduction of highly effective and power efficient biological mechanisms. Imitating these mechanisms offers enormous potentials for the improvement of our life and the tools we use. Gabriel Martin Nelson, In his report titled “Learning about Control of Legged Locomotion using a Hexapod Robot with Compliant Pneumatic Actuators”, he describes efforts to get a biologically-inspired hexapod robot, Robot III, to walk. Robot III is a pneumatically actuated robot that is a scaled-up model of the *Blaberus discoidalis* (cockroach). It uses three-way solenoid valves, driven with Pulse- Width-Modulation, and off-the-shelf pneumatic cylinders to actuate its 24 degrees of freedom. Single-turn potentiometers and strain gage load cells provide joint angle sensing and three axis foot force sensing respectively.

Daniel Adam Kingsley, [9]

In his paper “A Cockroach Inspired Robot with Artificial Muscles”, he explained purpose of research into legged locomotion. Legged robots are complex mechanisms, and their development can be greatly aided by insights into the mechanisms—both physical and control—by which animals loco mote. This text presents the design methodology used for the development of the fifth such biologically inspired robot at Case: Robot V. The robot is based on the death head cockroach, *Blaberus discoidalis.* It has twenty-four degrees of freedom (DOF). Actuation is by braided pneumatic actuators, and coupled with a valve system that allows air to be trapped within the actuators; numerous beneficial muscle-like properties were produced. Most importantly, this system enabled rapid response to perturbation, much like “reflexes” exhibited by animals. The robot is controlled by a hierarchical control system, and the operation of the inter leg coordination mechanism, a variant of the distributed network of the responsible for stick insect interleg coordination proposed by Cruse, is discussed in detail.

Abhijit Mahapatra, and Shibendu Shekhar Roy, [5]

In this study, “Computer Aided Dynamic Simulation of Six-Legged Robot” kinematics and dynamic simulation of a six-legged robot is performed based on virtual prototyping technology. Modeling and simulation of six legged robot with three joint legs are carried out with CATIA solid modeler, Sim Designer and ADAMS multi body dynamic solver. Tripod periodic gait pattern was generated varying the cycle time as well as stroke of the swing of the legs. Variation of joint torques and aggregate center of mass of the robot during periodic gait were analyzed. The simulation result provides theoretical basis for developing algorithm for robot motion control.

C. Mahfoudi, K.Djouani, M.BouazizandS. Rehak, [8]

This paper “Dynamic Modeling and Control in Operational Space of An Hexapod Robot” comments real times hexapod robot for control. Based on an operational trajectory planner, a computed torque control for the leg of hexapod robot is presented. This approach takes into account the real time force distribution on the robot legs and the dynamic model of the hexapod. First, Kinematic and dynamic modeling are presented. Then, a methodology for the optimal force distribution is given. The force distribution problem is formulated in terms of a nonlinear programming problem under equality and in equality on straits. The friction on strains is transformed from nonlinear inequalities into a combination of linear equalities and linear inequalities. Therefore, the overall hexapod computed torque control is presented. Simulations are given in order to show the effectiveness of the proposed approach.

Shibendu Shekhar Roy, Ajay Kumar Singh, and Dilip Kumar Pratihar[4]

In their paper, “Analysis of Six-legged Walking Robots”, an attempt has been made to carry out kinematic and dynamic analysis of a six-legged robot. A three-revolute (3R) kinematic chain has been chosen for each leg mechanism in order to mimic the leg structure of an insect.

Denavit–Hartenberg (D-H) conventions are used to perform kinematic analysis of the six-legged robot. The direct and inverse kinematic analysis for each leg has been considered in order to develop an overall kinematic model of a six-legged robot, when it follows a straight path. It is important to mention that trajectory generation problem during the support phase has been formulated as an optimization problem and solved using the least squared method. Lagrange-Euler formulation has been utilized to determine the joint torques. The developed kinematic and dynamic models have been examined for tripod gait generation of the six-legged robot.

1.4 Closer review of Literature survey

Referring to above topics of mentioned authors, we come across some new fields which are very much interesting and have lot to learn. Researchers worked deeply on this topic, understand some very complicated techniques, then analyzed and implement them in actual practice. They come to conclusion based on that this paper reviews worked perform in various bio robotics laboratories in different universities. Inspiring from them we can have better view and value of nature capabilities while studying its models to learn what can be extracted, copied or adapted.

II. DESIGN OF HEXAPOD

2.1 General aspect of Leg Design and steering

The Hexapod has two separate frames: upper and lower. Each is installed with one group of legs, which have separate two DOF for each leg as shown. The body propelling motion can be generated by total 12 DOF. Two frames are connected by a rotary joint at their geometric centers. When two frames rotate at an angle relative to each other using an actuator, the Hexapod can be steered. For example,

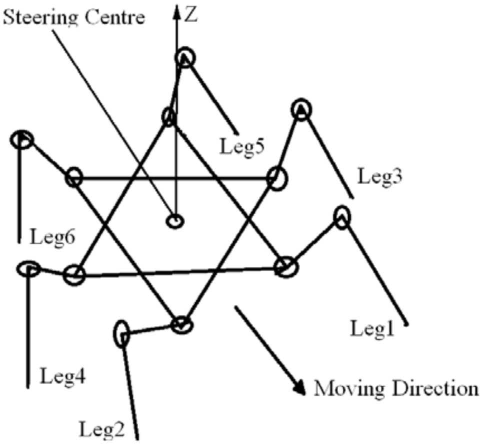
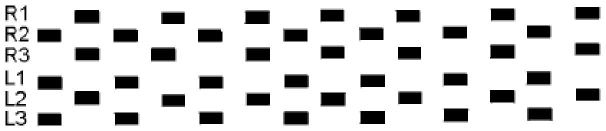


Fig.2.1: Basic Mechanism

2.2 Algorithm for Legs

In this design we have selected tripod gait for robot locomotion. The robot is assumed to describe a continuous alternating tripod gait (refer to Fig. 3) that consists of two main phases. In the first phase, legs: 1, 4, and 5 are in support and moving backwards at a specified trapezoidal velocity profile, while legs: 2, 3, and 6 are in their swing phase, moving forward to their next footholds. Each supporting foot tip follows a straight-line trajectory on the ground parallel to the trajectory of other supporting feet. [6]

Algorithm for Tripod gait:



2.3 CAD Modeling

A three dimensional CAD model of Hexapod robot can be developedin any CAD software assuming any suitable dimensions and material for legged robot. Each leg consists of three links, namely link 1(femur), link 2(tibia). Different parts of robot will be assembled in right manner. Then we will get mass properties of robot i.e. total volume of robot, total area covered, etc.

III. HEXAPOD ANALYSIS

To derive the kinematic model, the following assumptions are made: (a) The robot moves forward in a straight path on flat surface with alternating tripod gait. (b) The trunk body is held at a constant height and parallel to the ground plane during Locomotion. (c) The center of gravity of the trunk body is assumed to be at the geometric center of the body.

3.1 Kinematic Analysis: [3]

1. No. of joints n links n axis

Considering Leg1 as shown in Fig.3.1.

No. of Links (N): 2, No. of Joints (j): 2, No of Frames (f): 3

2. Selecting Home Position and Defining Z axis:

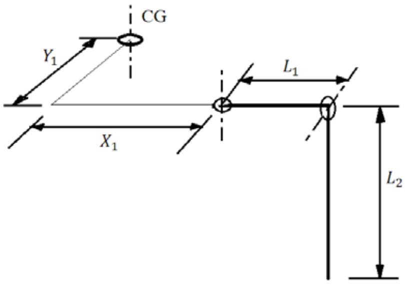


Fig.3.1.Home position of Leg

3. Frame assignment:

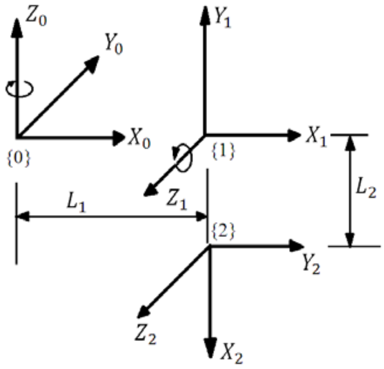


Fig.3.2.Frame Assignment of Leg

After frame assigning, we should formulate the table for joint link parameter. For example,

	a	α°	D	□°	C	S	Cα	Sα
Femur	l_1	90°	0	$\Box_1^o$	C	S	0	1
Tibia	l_2	0°	0	$\Box_2$-90°	C	S	1	0

5. Forward Kinematic Model:

$$T0^{2} = \begin{pmatrix} \cos \Box_1 * \sin \Box_2 & \cos \Box_1 * \cos \Box_2 & \sin \Box_1 & \cos \Box_1 *(l_1 + l_2 * \sin \Box_2) \\ \sin \Box_1 * \sin \Box_2 & \cos \Box_2 * \sin \Box_1 & -\cos \Box_1 & \sin \Box_1 *(l_1 + l_2 * \sin \Box_2) \\ -\cos \Box_2 & \sin \Box_2 & 0 & -(l_2 * \cos \Box_2 \\ 0 & 0 & 0 & 1 \end{pmatrix}$$

Considering Leg1 is at, X1, Y1 and Z1 distance from Center of Gravity (cg) of the Hexapod

$$^{cg}T2 = \begin{pmatrix} \cos \square_1 * \sin \square_2 & \cos \square_1 * \cos \square & \sin \square_1 & \cos \square_1 *(l_1 + l_2 * \sin \square_2) +X1 \\ \sin \square_1 * \sin \square_2 & \cos \square_2 * \sin \square_1 & -\cos \square_1 & \sin \square_1 *(l_1 + l_2 * \sin \square_2) +Y1 \\ -\cos \square_2 & \sin \square_2 & 0 & -(l_2 * \cos \square_2) + Z1 \\ 0 & 0 & 0 & 1 \end{pmatrix}$$

6. Inverse Kinematics: [3]

According to obstacle dimensions we have to select step size. Let it be d = x mm

Hence we can obtain,

$$\square_1 = a * \tan 2 (Dy, dx) , \quad \square_2 = a * \tan 2 (\pm\sqrt{[1 - (d_2 / l_2)^2}]$$

Compare the results with actual insect motion [kingsley-page 30], if the values are satisfying go further.

Motion of Robot from P to Q:

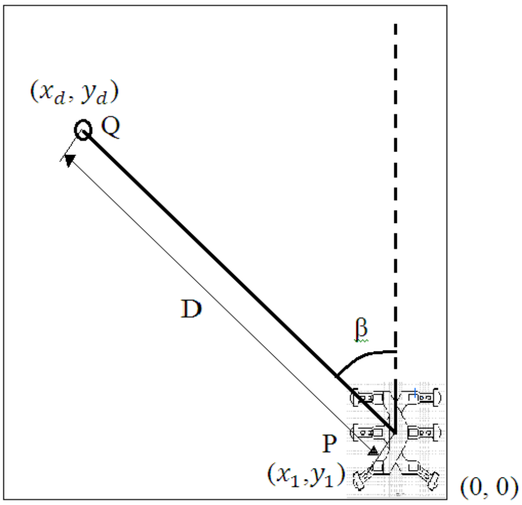


Fig.3.3. Hexapod moving in 2D space

We can calculate distance (d) covered by leg in one step and D is distance between P and Q

$$D= \sqrt{(X_d-X_1)^2 + (Y_d-Y_1)^2}$$

β is the angle by which Hexapod to be rotated,

$$\beta= a*\tan 2[(X_d-X_1), (Y_d-Y_1)]$$

Therefore, No. of steps (Ns) required for Hexapod to move from P to Q are, Ns = (D/d)

7. Jacobean and Singularities:

We have to check for Jacobean singularities to predict limitations of movements of leg. It is done by,

$$T_0^2 = \begin{pmatrix} -\sin \square_1 *(l_1 + l_2 * \sin \square_1) & l_2 * \cos \square_1 * \cos \square_2 \\ \cos \square_1 *(l_1 + l_2 * \sin \square_2) & \cos \square_2 * \sin \square_1 \\ 0 & l_2 * \sin \square_2 \\ 0 & \sin \square_1 \\ \cos \square_1 & \end{pmatrix}$$

3.2 Dynamic Analysis:

Now we have to calculate force acting on centre of gravity and legs of hexapod. For that measure the distance of 1st joint from CG. Then take total weight of hexapod. To assure the stability we should assume the hexapod is stationary and standing on three legs. Hence weight will be divided for each leg. Hence we get the reaction force ($F_{r)}$ in upward direction. Now for the friction force assume the friction coefficient (μ) for ground. Therefore, friction force will be,

$F_{f =} \mu * F_r$ N

Using above values moments on X and Y axis can be calculated, which is used in further calculation of Torque.

3.3 Velocities:

Referring biological data, the cycle time and maximum velocity (V) of trunk body are assumed, and angular velocities ω_1 and ω_2 will be calculated from the formula, V = (r* ω) for link1 (Femur) and for link 2 (Tibia) r.

3.4 Torque Calculation:

For deriving the dynamic equations and finding joint torques' variations over the locomotion cycle, Lagrange- Euler formulation has been used. The direct application of Lagrangian dynamics formulation together with Denavit- Hartenberg's link coordinate representation results in a convenient, compact, systematic algorithmic description of the equations of motion. A systematic derivation of Lagrange-Euler equations yields a dynamic expression that can be written in the vector-matrix formats given below. [4]

$\tau = M (\theta) + H (\theta,) + G (\theta) + F$

Where, M (θ) is the 2×2 inertia matrix of the leg

H is a 2×1 vector of centrifugal and Carioles terms,

G (θ) is a 2×1 vector of gravity terms

F is the 3×1 vector of ground contact forces

$$M (\theta) \ddot{\theta} = \begin{pmatrix} M_{11} & M_1 \\ M_{21} & M_{22} \end{pmatrix} \qquad H (\theta, \square\, \theta) = \begin{pmatrix} H_1 \\ H_2 \end{pmatrix} \qquad F = \begin{pmatrix} F_x \\ F_y \\ F_z \end{pmatrix} \qquad \text{Hence} \quad J^T F = \begin{pmatrix} T_1 \\ T_2 \end{pmatrix}$$

IV. Conclusion:

Both the kinematic as well as dynamic analyzes of a Six legged robot can be carried out and simulated for different values. The direct and inverse kinematic analysis for each leg has been conducted in order to develop the overall kinematic model of a Hexapod. The problems related to trajectory generation of legs can be solved for both the swing and support phases of the robot. Joint torques can be calculated using Lagrange-Euler formulation of the rigid multi-body system. The developed kinematic and dynamic model can be examined for tripod gait generation of the six-legged robot. As per our objective, It s found that as we increase the link lengths Torque required on joints is increasing. Solution can be optimized to get link lengths depending on space requirement and application.

Future Work:

The Hexapod can be made more flexible by using different link lengths for Front, Middle and Hind legs. Intelligence can be induced by introducing Sensors and vision. Range of motion and Moments available at each joint are the greatest concern as it is important for achieving stance and insect like walking.

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